

Achieving Nano Amp I_Q Voltage Supervision in Automotive, Wide- V_{IN} Applications

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ABSTRACT

This application note will focus on designing Texas Instrument's voltage supervisors into automotive, wide- V_{IN} applications, for increased robustness/protection, while still maintaining high system efficiency.

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1 Introduction

As car manufactures continue to make cars more safe, high performance electronics become more prominent in cars.

Many of these electronics must be able to withstand all the harsh conditions experienced in an automobile, while continuing to operate at a high level of accuracy. Many automotive systems implement some form of voltage supervision. Voltage supervision creates another layer of protection in developing a more robust design to the varying (and extreme) conditions automotive electronics must handle gracefully.

Without implementing voltage supervision, overvoltage or undervoltage of the power domains contained in the system could cause incorrect operation or destruction of the devices. This additional protection can come at a cost though, that is, a hit to the system's efficiency figure, especially at high input voltages. This application note will focus on designing Texas Instrument's voltage supervisors into automotive, wide- V_{IN} applications, for increased robustness/protection, while still maintaining high system efficiency.

2 Voltage Supervision Requirement

2.1 Automotive Environment Challenges

As mentioned earlier, automotive designs have stringent requirements to ensure a high-level of functional safety for the electronic systems. Voltage supervisors, specifically supervisors monitoring off-battery voltage, must be able to handle the supply transients seen at the input. Many of these transients also can be detrimental to downstream components, such as: power converters, MCUs, or other electronics, which may not have an output to signal safe (or accurate) operation. By implementing a supervisor into your automotive systems, the detrimental and/or costly consequences of your power system failing can be prevented. To better understand some of the transients that occur on an automotive battery, please read: application note [SNVA780: Designing High-Performance, Low-EMI Automotive Power Supplies](#).

The transients often experienced in automotive applications can be handled by correctly selecting safety components, such as, a TVS (transient voltage suppression) device and series Schottky diode (or smart diode) for reverse polarity protection on the battery. Unfortunately, voltage suppression/protection devices cannot prevent events such as a cold crank condition, where the car battery could drop to as low as 4.2V, or similarly, a situation in which the battery is not being charged correctly up to its nominal value of 12V, or is being over charged. A voltage supervisor can alert the system (quickly) when events like this occur and enable the system to respond correctly.

By being able to accurately monitor the battery voltage, the additional electronics in the system can be properly sequenced. Some of these electronics may be powered directly off-battery. By being able to measure and report faults on the battery's voltage, the system can ensure that all devices are properly initialized, do not enter an invalid logic state, and/or are operating correctly.

While some DC/DC power converters may output a "power good" signal to show that the converter has reached its nominal value, some do not. Either way, a voltage supervisor can provide additional functional safety in your design. This additional safety comes from often having higher accuracy and being able to adjust the threshold, time delay, and hysteresis of the voltage supervisor.

Overvoltage and undervoltage detection is often needed to be implemented for safety-critical, off-battery applications. Often a bigger focus is put on undervoltage detection for battery voltage supervision, since the downstream DC/DC converter could drop out from undervoltage input. Use of wide- V_{IN} DC/DC converters or overvoltage clamps obviate the need for overvoltage detection. The design focus of this application note will be on undervoltage detection.

2.2 Low-Power Automotive Applications

For the case of voltage supervisors, performance metrics designers are looking at are: threshold accuracy, response time, and low I_Q . Some modern "wide- V_{IN} " voltage supervisors can have a variable voltage threshold to provide flexibility to the designer, though often can't directly sense 12V to 36V. This leaves us with using a voltage divider to be able to both adjust the voltage threshold, as well, not exceed the absolute maximum on the sense (or V_{DD}) pin.

Needing a voltage divider could have been a deal breaker for certain applications, due to increased power loss. Fortunately, the next-generation voltage supervisors, such as TPS3840-Q1, has an extremely low quiescent current (I_Q) of 350nA. This allows for additional headroom on current consumption, which can be crucial for some automotive, always-on systems, which can have standby current budgets as low as 100uA.

In the next section, we will go over a design example illustrating this and showing the minimal effect (on efficiency) by adding a voltage divider.

3 Design Example: TPS3840-Q1 for Low I_Q Wide- V_{IN} Applications

3.1 Design Key Features

TPS3840-Q1 has many key features that make it appealing for an automotive application. As mentioned earlier, the TPS3840-Q1 has industry leading performance that allows it to achieve a very high system efficiency figure. The typical I_Q is 350nA, as well, it can operate over a wide voltage range from 1.5V to 10V (absolute max = 12V). The combination of these two design features make it especially appealing for low-power, always-on, direct-off-battery supervision.

Additionally, TPS3840-Q1 has a very low V_{POR} , programmable time delay, and comes in both open-drain and push-pull configuration. The combination of all these aspects makes it a very flexible device for varying sub-system requirements.

3.2 Block Diagram

The general power tree in automotive (12V battery) applications can be seen in Figure 1. In this design example, we are highlighting the ability for low power (1mW), direct-off battery voltage supervision. In addition, voltage supervision can be done on the pre-boost stage (if needed), buck converter, and LDO outputs for additional power monitoring (“power good” signal).

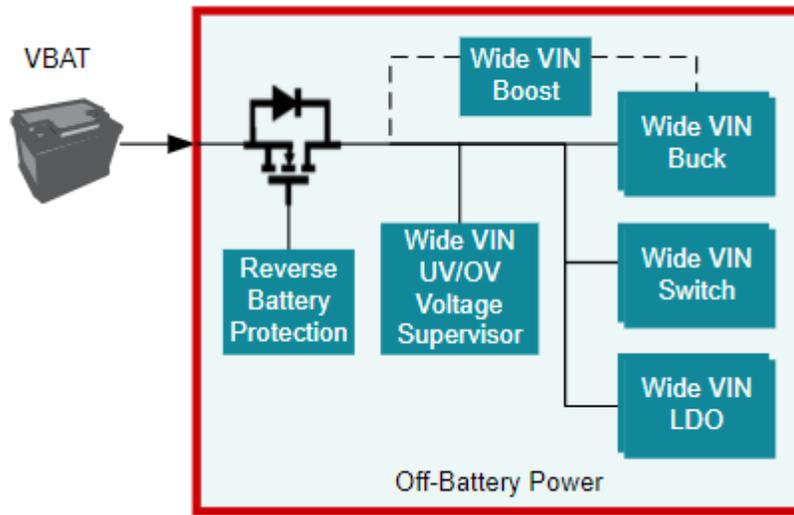


Figure 1. Direct-off battery voltage supervision

3.3 Design Figures

Highlighted in Table 1 are the design requirements. The supervisor must be able to withstand a wide range (up to 36V or 42V) of voltage at its input. To achieve that, a voltage divider will be needed to be implemented. Even with a voltage divider, this design can achieve a very high efficiency figure due to TPS3840-Q1’s low (350nA) I_Q .

Table 1. Design Requirements

	DESIGN #1	DESIGN #2
$V_{BAT,min}$	4.2V	4.2V
$V_{BAT,nom}$	12V	12V
$V_{BAT,max}$	36V	42V
$V_{DD,max}$ (supervisor)	10V	10V
V''_{IT-}	7.7V	7.7V
V_{IT+}	1.7V*	1.7V*
V_{IT-}	1.6V	1.6V

*The hysteresis is defined in the datasheet, though, can be varied by an external resistor network. To better understand externally setting hysteresis value, read [SLVA360: Adding Hysteresis to Supply Voltage Supervisor](#)

Note: V_{IT-} signifies the threshold sensed at the supervisor’s input. V''_{IT-} signifies the pre-divided voltage, or the voltage threshold on the battery (post protection diode) that needs to trigger a fault. This nomenclature is maintained throughout the rest of the application note.

3.4 TPS3840-Q1 Schematic

Figure 2 illustrates the schematic for the low-power supervisor design. The design implements TPS3840-Q1 to achieve a very high efficiency figure due to its ultra-low (350nA) I_Q . A Q-grade part was selected for additional assurance that the device will be able to withstand the harsh conditions it might see over lifetime.

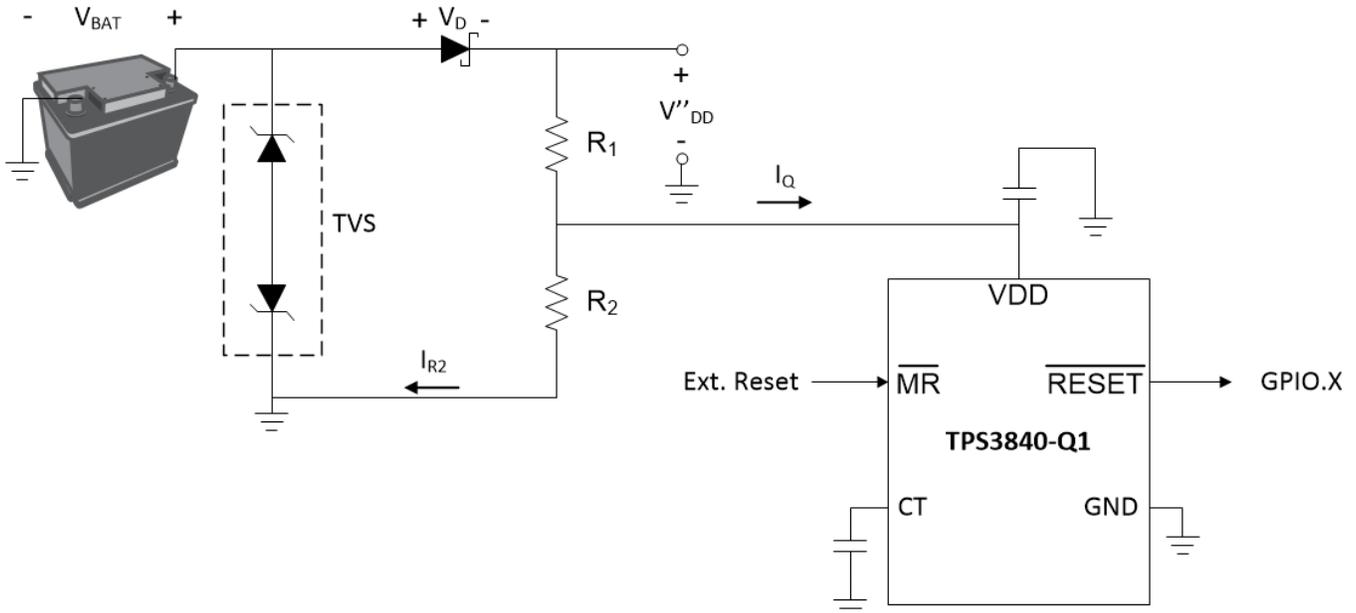


Figure 2. TPS3840-Q1 Schematic

3.4.1 Component Selection

The design implemented a voltage divider to withstand a voltage range. The absolute maximum voltage that TPS3840-Q1 can sense is 10V. A voltage divider had to be implemented so that the device would not become damaged when large transients occur on the 12V battery. Reasonably sized resistors were selected ($<100k\Omega$) for the voltage divider. While selecting lower resistor values may increase the current draw from the battery, this can enable additional safety. The additional safety/accuracy is created by having a lower temperature coefficient, lower tolerance, and higher stability over lifetime (of the resistors).

1. Determine R_2 , given $R_1 = 100k\Omega$ and $V''_{IT(-)} = 7.7V$,

- The design aimed to have the max voltage the device will see to be less than 10V. The maximum resistance value ($R_{2,max}$) that R_2 can be is determined by solving Equation 1 for where it is equal to 10V ($V_{DD,max}$) and the battery is at its maximum voltage ($V_{BAT,max}$). Choosing a resistor value less than or equal to $R_{2,max}$ will ensure the inequality (Equation 1) is true.
- The design must also be satisfied for the minimum voltage that will be seen on the battery ($V_{BAT,min}$). The minimum resistance value can be determined by solving Equation 2 for where it is equal to 300mV (V_{POR}) and the battery is at its minimum voltage ($V_{BAT,min}$). Choosing a resistor value greater than or equal to $R_{2,min}$ will ensure the inequality (Equation 2) is true.
- With the given resistance range ($R_{2,min}$ to $R_{2,max}$), given $V''_{IT(-)}$, and the available voltage thresholds for order in the TPS3840-Q1 family, the appropriate resistance value can be determined.

$$V_{DD,max} = 10V \geq \frac{R_2}{R_1 + R_2} (V_{BAT,max} - V_D) \quad (1)$$

$$V_{POR} = 300mV \leq \frac{R_2}{R_1 + R_2} (V_{BAT,min} - V_D) \quad (2)$$

$$R_2 = \frac{V''_{IT(-)}}{V''_{IT(-)} - V_{IT(-)}} (R_1) \quad (3)$$

2. Determining Component Values

Table 2. Determining Component Values

	DESIGN #1	DESIGN #2	UNIT
Selected R_1	100	100	$k\Omega$
V_D	0.3	0.3	V
$V_{BAT,max}$	36	42	V
$V_{BAT,nom}$	12	12	V
$R_{2,max}$	38.91	31.55	$k\Omega$
$V_{BAT,min}$	4.2	4.2	V
V_{POR}	0.3	0.3	V
$R_{2,min}$	8.33	8.33	$k\Omega$
V_{IT-}	1.6	1.6	V
V''_{IT-}	7.7	7.7	V
R_2	26.23	26.23	$k\Omega$
Selected R_2	26.70	26.70	$k\Omega$
Actual V''_{IT-}	7.59	7.59	V

3.4.2 Threshold Selection

Ideally, from a signal to noise ratio point of view, a designer would like to implement a voltage threshold that is as high as possible. While having a high voltage threshold is important, additionally, having sufficient headroom to accommodate for the large inductive spikes that occur as a result of the wiring harness and load dump condition must be considered. TPS3840-Q1 is capable of a large voltage range (10V) and can implement a voltage divider to get additional headroom for the automotive transients. The voltage divider can be scaled for a larger ratio, such that, the headroom of the supervisor could be further widened. This choice would have called for a lower voltage threshold and larger resistors. Both of these changes would be non-ideal, with the disadvantage of the latter being discussed in detail in the earlier section ([Section 3.4.1](#)).

3.4.3 Power Analysis

In [Table 3](#) demonstrated is the power consumption of the device. Called out in the table is the additional power loss (ΔP_{LOSS}) associated with the bias current for the voltage divider. While this causes power consumption to increase, the effect is relatively negligible due to the devices' low (350nA) I_Q . Below are the steps needed to be taken in performing a power analysis on the TPS3840-Q1 design. All of the figures needed for the computations can be found in [Table 3](#).

1. Determine nominal supply voltage

$$V_{DD,norm} = \frac{R_2}{R_1 + R_2} (V_{BAT} - V_D) \quad (4)$$

2. Determine voltage divider bias current, I_{R2}

$$I_{R2} = \frac{V_{DD,norm}}{R_2} \quad (5)$$

3. Determine power consumption of design

$$P_{TOTAL} = V_D(I_{R2} + I_Q) + R_1(I_{R2} + I_Q)^2 + R_2(I_{R2}) + V_{DD}(I_Q) \quad (6)$$

4. Determine power consumption of TPS3840-Q1 (P_{VS})

$$P_{VS} = I_Q * V_{DD,norm} \quad (7)$$

5. Determine additional power consumption due to voltage divider

$$\Delta P = P_{TOTAL} - P_{VS} \quad (8)$$

Table 3. Power Analysis

	DESIGN #1	DESIGN #2	UNIT
$V_{BAT,nom}$	12	12	V
V_D	0.3	0.3	V
I_Q	350	350	nA
Selected R_1	100	100	k Ω
Selected R_2	26.7	26.7	k Ω
$V_{DD,nom}(V_{BAT} = 12V)$	2.53	2.53	V
I_{R2}	94.72	94.72	μ A
P_{TOTAL}	1.173	1.173	mW
P_{VS}	0.88	0.88	μ W
$\Delta P = P_{TOTAL} - P_{VS}$	1.172	1.172	mW

3.5 Design Verification

A concern with the above design is that accurate voltage supervision is able to be maintained over the voltage range specified: 4.2V to 36V/42V. If appropriate circuit protection is done, that is, a correctly selected TVS and voltage divider, then the device won't have its absolute maximum rating violated. For the low-end of the voltage range, it needs to be verified that the device will continue to operate correctly.

The lower bound on the voltage range was specified for a typical cold-crank condition on a car battery. Many of Texas Instruments' customers follow a "typical" cold-crank profile, developed in-house. To ensure the TPS3840-Q1 design will be able to handle a cold-crank condition, performed were a few popular, automotive (cold) crank profiles.

The scope of the testing below was to ensure that normal operation was maintained under typical cold-crank conditions. This was verified by observing that as the input fell to its minimum value, which could be as low as 5V, the output remained both defined and accurate.

The below test setup (Figure 3) was used to verify device operation. It is worth noting, that as the battery drops to 5V, at the device's V_{DD} pin (post-voltage divider), the voltage is approximately 880mV. The datasheet specification for minimum V_{DD} voltage ($V_{DD, min}$) is 1.5V. While $V_{DD, min}$ is being violated under cold-crank condition (VW80000), the device's output stage can continue to drive the output correctly. The only caveat to have a correctly operating output stage is keeping the input above V_{POR} , hence the auxiliary condition () for selecting the voltage divider.

Below Figure 4, Figure 5, Figure 6 are oscilloscope captures of three separate (cold) crank profiles performed on the TPS3840-Q1. To ensure safe operation for the design, a zoomed in oscilloscope capture of the output waveform is shown. It can be seen that the output is both defined and accurate as expected.

To better understand the (cold) crank profiles performed in this test, please read [SLVU984: Automotive Cranking Simulator User's Guide](#). This user guide highlights the cold-crank simulator EVM used in this testing.

Additionally, two worst-case transients (13.5VIN to 4.2VIN and 13.5VIN to 42VIN) were done and waveforms recorded (Figure 7, Figure 8).

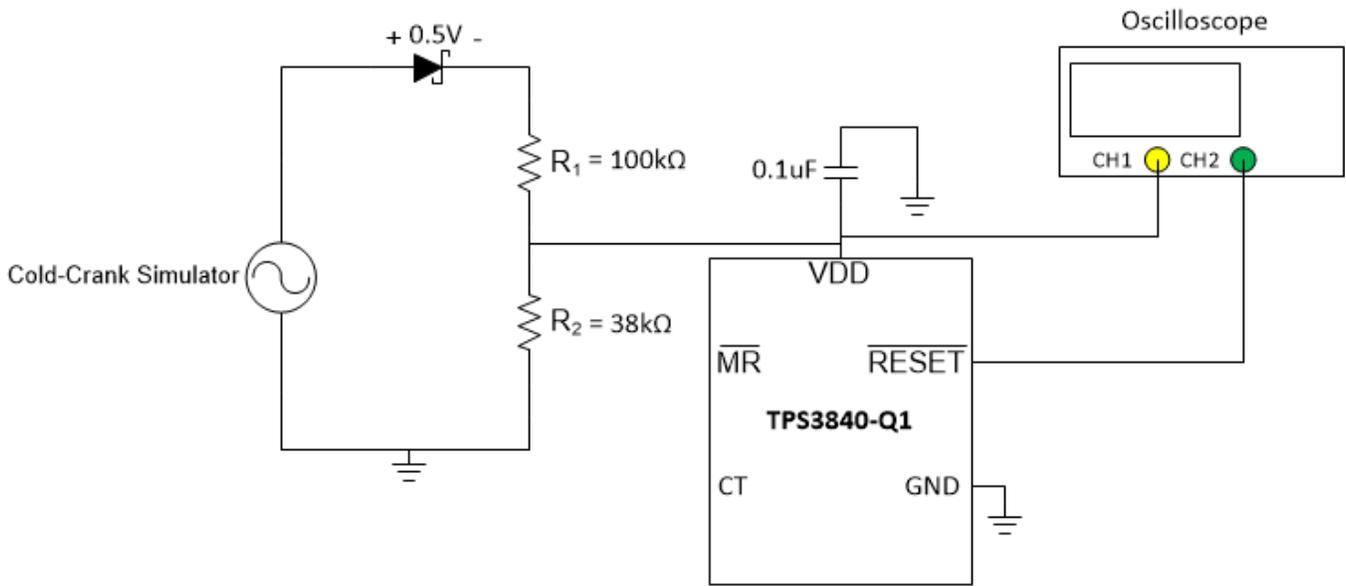


Figure 3. Cold-Crank Test Setup

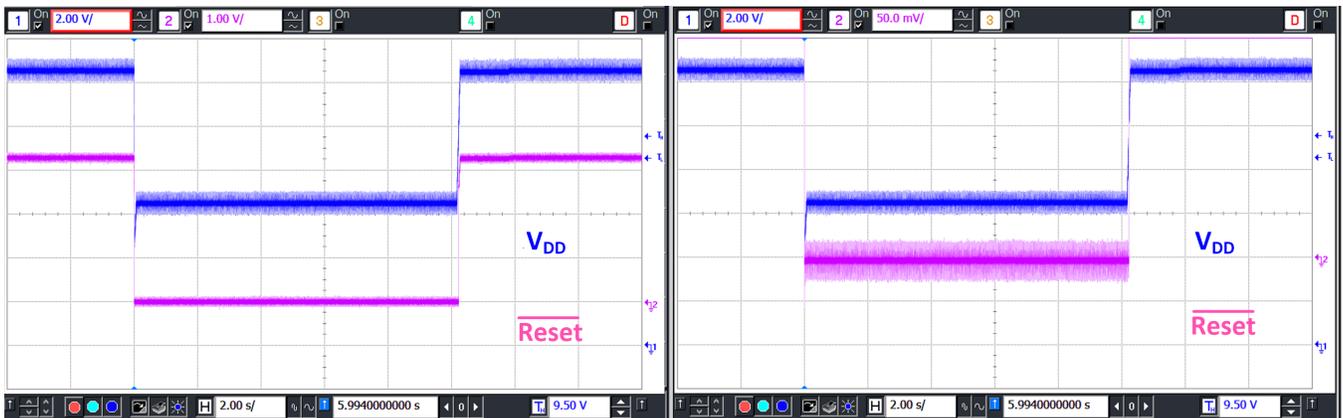


Figure 4. DaimlerChrysler Engine-Cranking Test Pulse, DC-10615

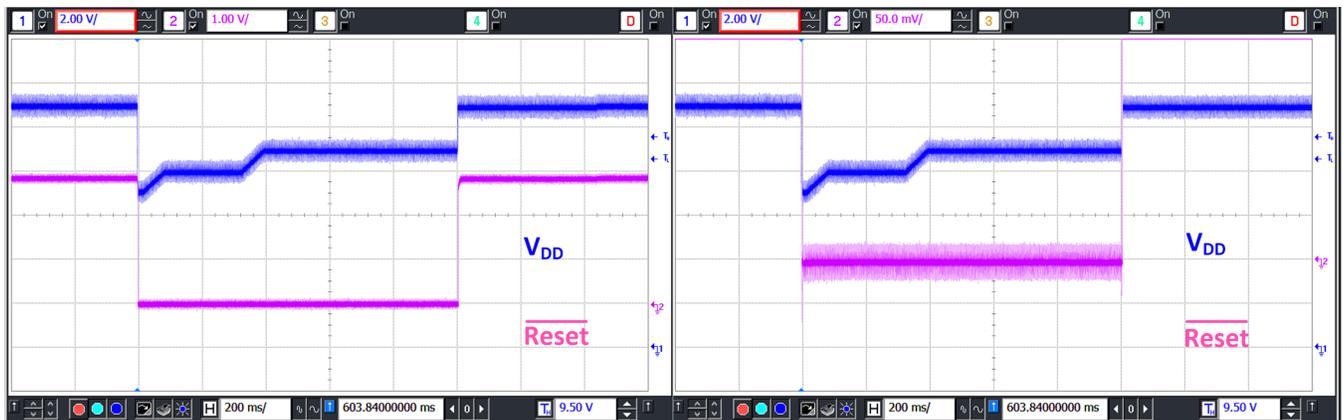


Figure 5. Volkswagen Warm-Start Test Pulse, VW80000

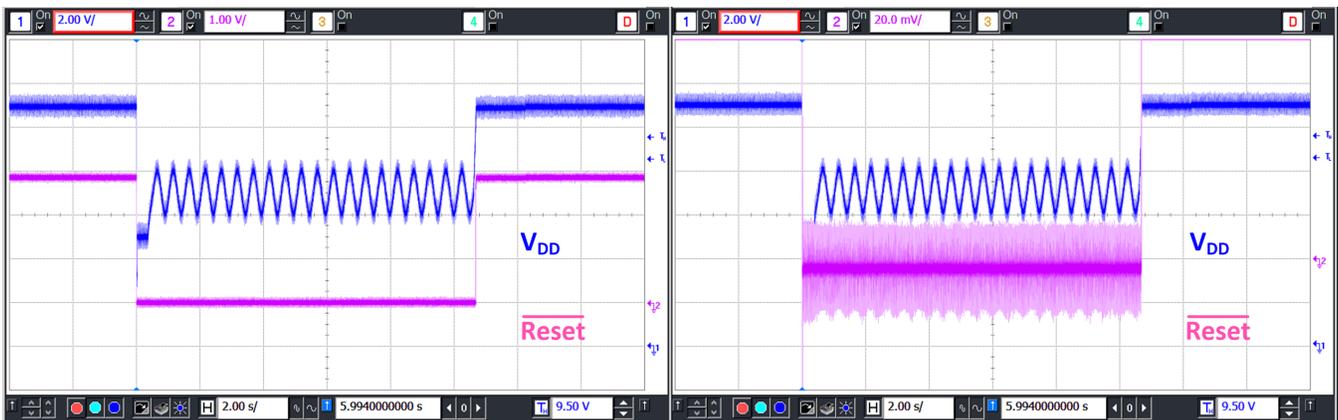


Figure 6. Volkswagen Cold-Start Test Pulse, VW80000

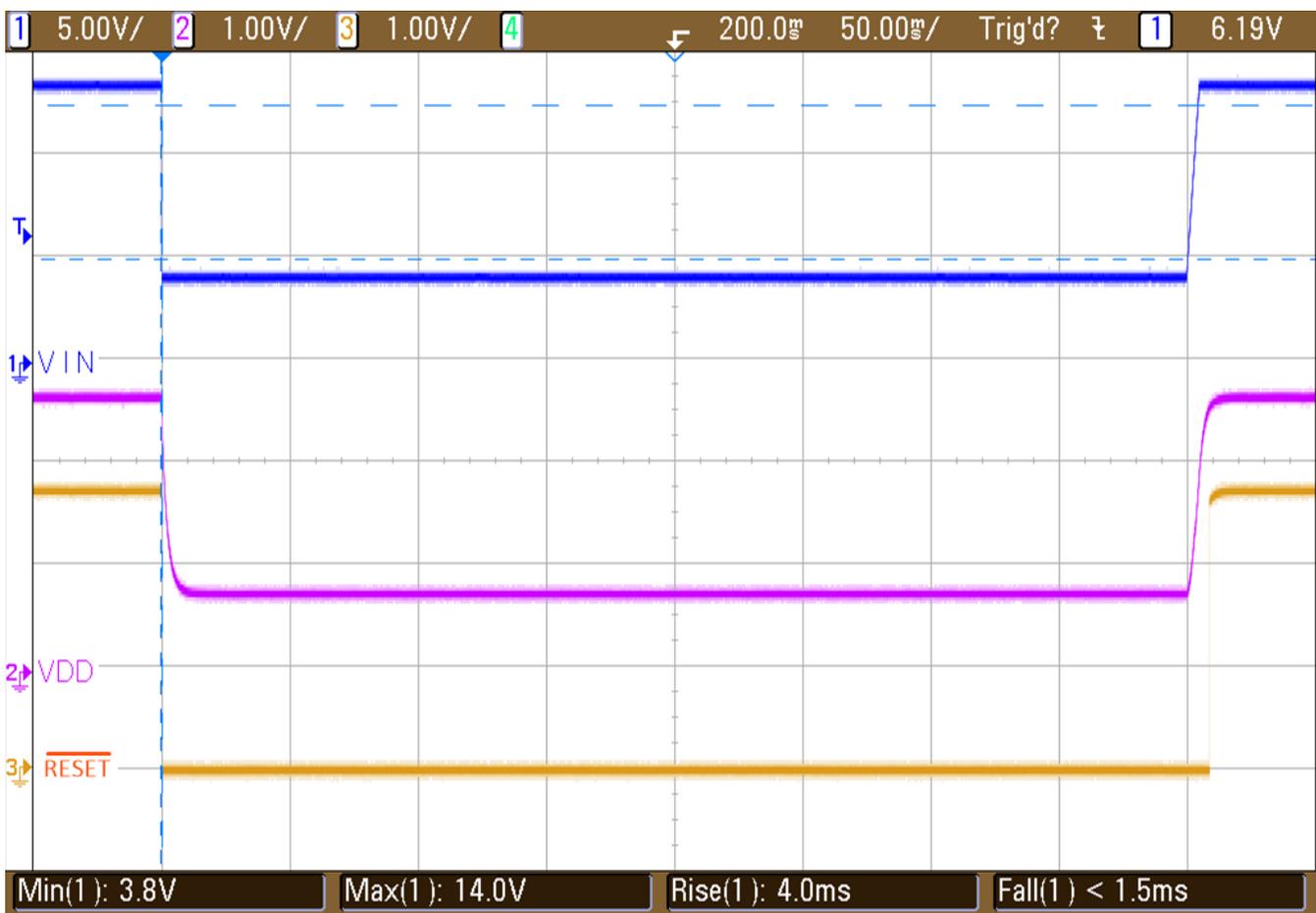


Figure 7. 13.5V_{IN} to 4.2V_{IN} Transient (Cold-Crank)

Note: The approximate parameters where used for the transient on VIN (the battery): fall time = 1ms, low time = 400ms, rise time = 4ms, low voltage = 4.2V, and high voltage = 13.5V. The voltage divider resistance values used for this testing were: $R_1 = 100k\Omega$ and $R_2 = 26.7k\Omega$

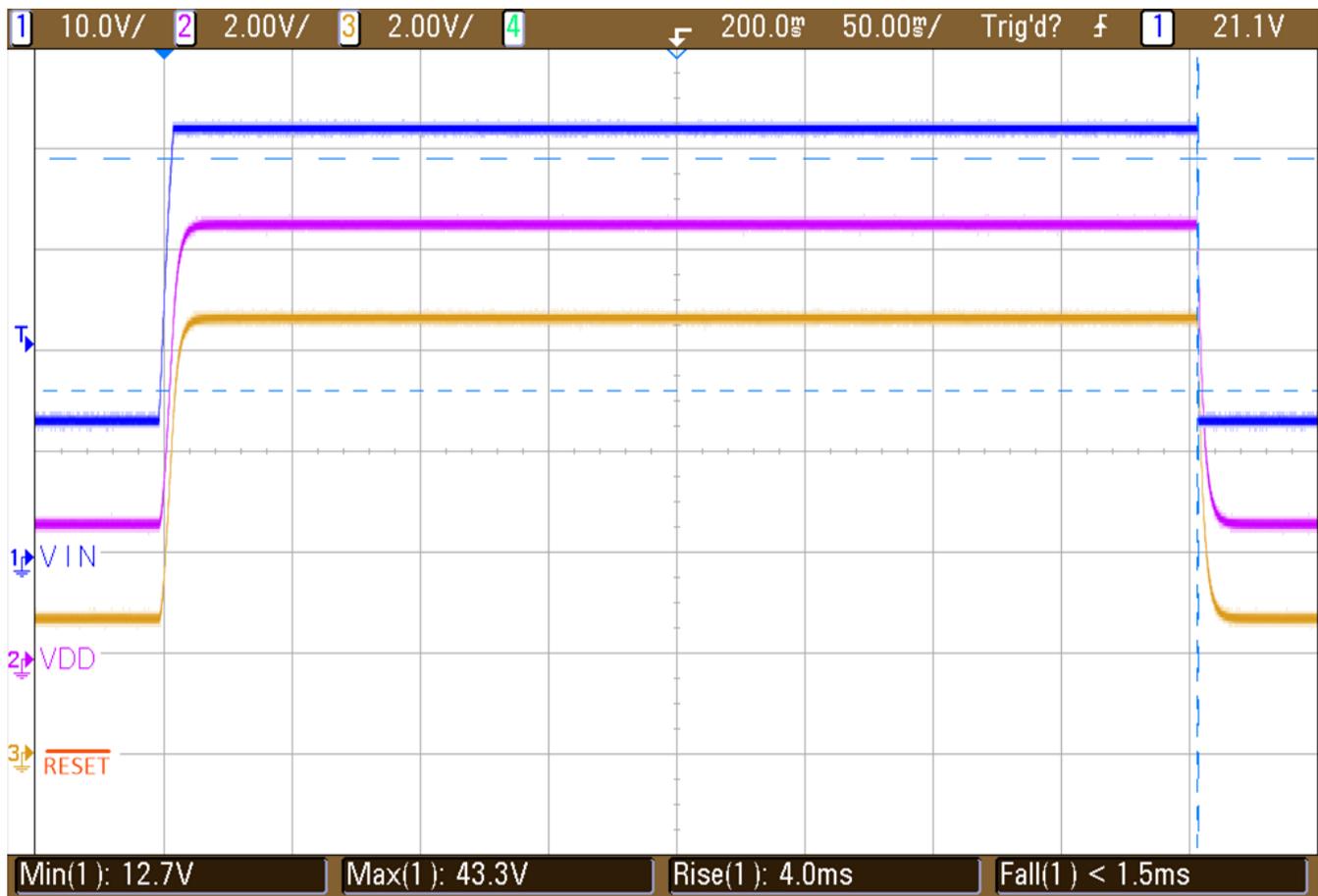


Figure 8. 13.5V_{IN} to 42V_{IN} Transient (Load-Dump)

Note: The approximate parameters where used for the transient on VIN (the battery): rise time = 4ms, high time = 400ms, fall time = 1ms, low voltage = 13.5V, and high voltage = 42V The voltage divider resistance values used for this testing were: $R_1 = 100k\Omega$ and $R_2 = 26.7k\Omega$

4 Summary

The TPS3840-Q1 serves as an excellent example of a device whose low- I_Q and wide-input range allows for direct-off-battery voltage supervision, while not sacrificing efficiency. Additionally, the devices' low V_{POR} and programmable delays make it very flexible to configure to your system's requirements or constraints.

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